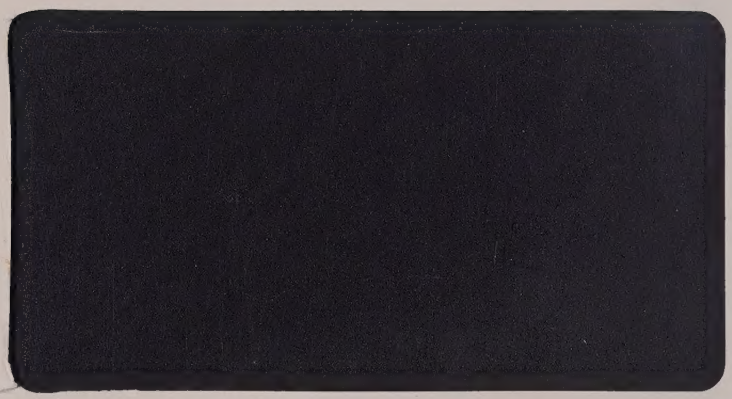
INSTRUCTION MANUAL

MODEL 660

GUARDED DC

DIFFERENTIAL VOLTMETER

KEITHLEY INSTRUMENTS



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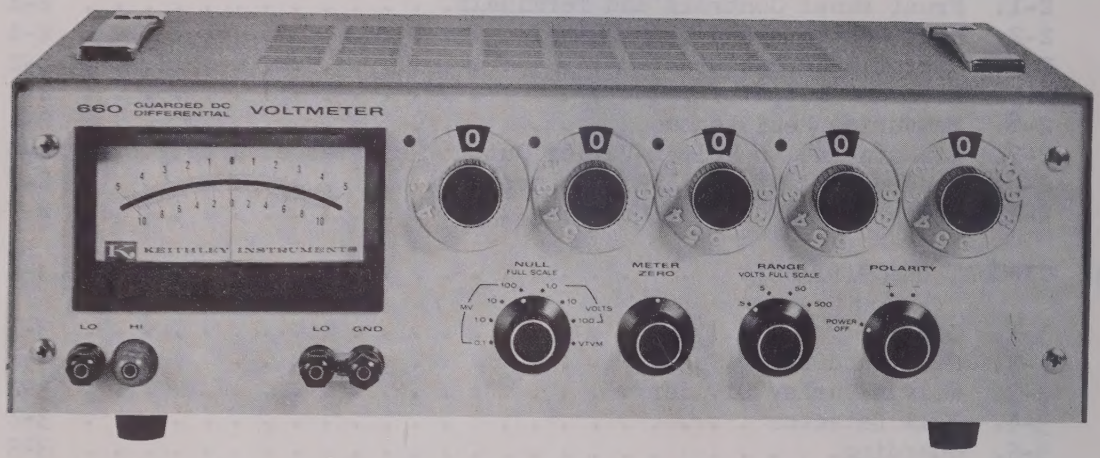


FIGURE 1. Model 660 Guarded DC Differential Voltmeter

SECTION 1. GENERAL DESCRIPTION

1-1. DESCRIPTION.

a. The Keithley Model 660 Guarded DC Differential Voltmeter is a precision null-balance or potentiometric voltmeter. It features 0.02% limit of error from 100 millivolts to 500 volts full scale, 0.005% repeatability, and a reference supply stable to 0.005% indefinitely without manual standardization. Maximum null sensitivity is ±100 microvolts full scale; resolution is within 2.0 microvolts.

b. Features for convenient use include: in-line digital readout with automatically lighted decimal points; 10 to 25-millivolt recorder output; input polarity switch; floating operation up to 500 volts off ground; fast overload recovery; better than 45 decibels of 60 cps rejection.

1-2. OPERATING MODES. The Model 660 can be used as a potentiometer or as a conventional vacuum tube voltmeter. As a potentiometer, it can measure from 100 millivolts to 500 volts full scale with ±0.02% limit of error and from 100 microvolts to 10 millivolts full scale within 20 microvolts. As a VTVM, the Model 660 can measure over 11 ranges from 100 microvolts to 500 volts full scale with an accuracy of ±3% of full scale. The instrument can also be used to measure resistances from 10 to 50,000 megohms within ±5%.

1-3. APPLICATIONS.

a. The Model 660 is used for measurements over a wide range. Typical applications in the microvolt region are the matching of semi-conductors and the monitoring of noise, transients and drift. High level voltage applications include power supply and meter calibration, and tube potential measurements.

b. Overall stability of 0.01% indefinitely makes the Model 660 useful in measurements of extended duration. Measurements of long-term power supply stability, long-term drift runs, and monitoring during environmental and reliability tests are possible uses.

c. The null-detector output permits use with potentiometric recorders and digital voltmeters equipped with automatic print-out. The Model 660 is useful in quality control, product development, inspection and production.

d. Floating operation to 500 volts is provided for measurements such as plate potential differences of balanced amplifiers.

1-4. ACCESSORIES.

a. The Model 6601A High Voltage Divider is a 100:1 divider which extends the range of the Model 660 to 5000 volts. The divider accuracy is ±0.01% and its input resistance is 10 megohms. The overall limit of error of the Model 660 with the Model 6601A is ±0.03%.

b. The Model 4000 Rack Mounting Kit adapts the Model 660 for standard 19-inch rack mounting. (Refer to paragraph 2-11).

1-5. SPECIFICATIONS.

AS AN ULTRA-STABLE POTENTIOMETER:

COMBINED STABILITY OF KELVIN-VARLEY DIVIDER AND POWER SUPPLY: ±0.01% indefinitely, after one-hour warmup. Temperature coefficient does not exceed 0.002% per °C.

REPEATABILITY: Within 0.005%.

MAXIMUM NULL SENSITIVITY: 100 microvolts full scale with 2.0-microvolt resolution.

LIMIT OF ERROR: ±0.02% of input voltage or 20 microvolts, whichever is greater, after 15-minute warmup.

INPUT RESISTANCE: Infinite at null, from zero to 500 volts.

POLARITY: Positive or negative, selectable by panel control.

FLOATING OPERATION: May be operated with up to 500 volts between LO and GND (chassis ground).

LEAKAGE RESISTANCE — LO TO GROUND: Greater than 10^8 ohms.

RESOLUTION:

Input Voltage Range	Maximum Dial Resolution (millivolts)	Maximum Usable Full Scale Null Sensitivity (millivolts)	Maximum Meter Resolution (microvolts)
50-500	10	10	100
5-50	1	1	10
0.5-50	0.1	0.1	2
0-0.5	0.01	0.1	2

AS A VTVM:

VTVM Range (positive or negative)	Input Resistance
500 volts	10 megohms
50 volts	10 megohms
5 volts	10 megohms
0.5 volt	10 megohms

TABLE 1 (sheet 1). Model 660 Specifications.

AS A VTVM ON NULL RANGES:

Null Range	Input Resistance (Slewing)
100 volts	10 megohms
10 volts	10 megohms
1 volt	10 megohms
100 millivolts	1 megohm
10 millivolts	1 megohm
1 millivolt	1 megohm
0.1 millivolt	100 kilohms

NOTE: Input resistance on 0.1-millivolt range can be increased; see paragraph 2-7.

VTVM ACCURACY: $\pm$3% of full scale on VTVM and null ranges.

DRIFT: Less than 10 microvolts, non-cumulative, after 15-minute warmup.

60 CPS REJECTION: Greater than 45 db.

GENERAL CHARACTERISTICS:

STABILITY OF 500-VOLT SUPPLY: $\pm$0.005% indefinitely, after 1-hour warmup.

STABILITY OF ZENER REFERENCE: 20 ppm per year and five ppm per ^{o}C.

LINE TRANSIENT REGULATION: Less than 5 ppm for 10% variation from 117 volts.

LINEARITY OF DIVIDER: 0.005%.

CHARACTERISTICS OF NULL DETECTOR OUTPUT:

Output: Adjustable 10 to 25 millivolts dc full scale, all ranges.
Output Resistance: 300 ohms maximum.
Noise: 2 microvolts peak-to-peak (referred to input).
Note: Recorder used must have input fully isolated. (10^{10} ohm minimum leakage resistance to ground.)

CONNECTORS: Input: Binding posts on front panel.
Output: Banana jacks on rear.

TUBE COMPLEMENT: One 0G3, five 12AX7, one 12BH7, two 12B4A, one 6CM8.

POWER: 105-125 volts or 210-250 volts, 50-60 cps, 75 watts.

DIMENSIONS (for bench use): 5$\frac{1}{2}$ inches high x 17$\frac{1}{2}$ inches wide x 13$\frac{1}{2}$ inches deep.

NET WEIGHT: 24 pounds.

TABLE 1 (sheet 2). Model 660 Specifications.

1-6. EQUIPMENT SHIPPED. The Model 660 Guarded DC Differential Voltmeter is factory-calibrated and is shipped with all components in place. Unless the order calls for rack-mounting, the Model 660 is shipped as a bench instrument. The shipping carton also contains the Instruction Manual.

1-7. REGISTRATION CARD. The registration card is attached to the front cover of the Instruction Manual. Please fill it out and mail it when you receive the instrument.

1-8. DAMAGE IN SHIPMENT. If the Model 660 is damaged or faulty when received, follow the instructions given at the back of the manual for reporting the defect.

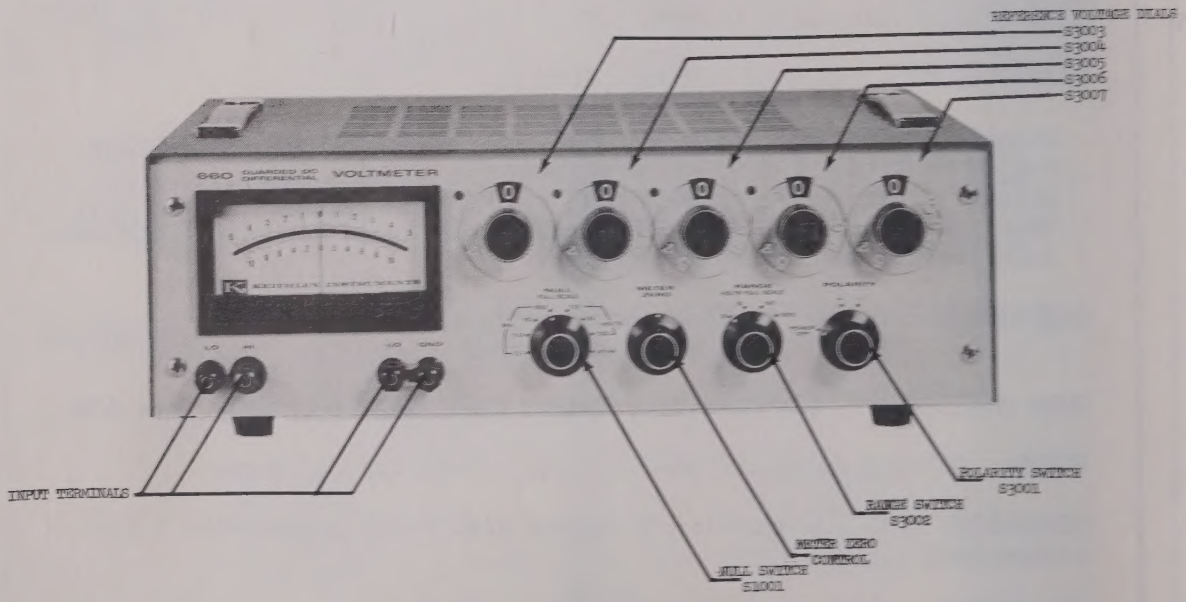


FIGURE 2. Model 660 Front Panel Controls.

SECTION 2. OPERATION

2-1. FRONT PANEL CONTROLS AND TERMINALS. (See Figure 2.)

a. POLARITY. The POLARITY switch turns the instrument on and selects the input polarity. The switch reverses the polarity of the internal power supply so both positive and negative voltages may be measured; it does not reverse the meter polarity.

b. NULL. The NULL switch sets the null detector sensitivity for seven decade ranges from 0.1 millivolt to 100 volts full scale. When the switch is in the VTVM position, the Model 660 operates as a conventional vacuum tube voltmeter for the four ranges of the RANGE switch.

c. RANGE. The RANGE switch adjusts the sensitivity of the VTVM in four steps: 0.5, 5, 50 and 500 volts full scale. It also determines the voltage across the Kelvin-Varley Divider and the position of the decimal point light between the five Reference Voltage Dials.

d. REFERENCE VOLTAGE DIALS. Five in-line dials at the top of the front panel set the reference voltage when the Model 660 is used as a potentiometer.

e. METER ZERO. The METER ZERO control adjusts the meter pointer to zero. The control is needed on only the 0.1 MV and 1.0 MV null ranges; on the other ranges, the pointer will normally be on zero without adjustment. The control has a range of approximately $\pm$50 microvolts.

f. INPUT TERMINALS. At the lower left front panel, the black LO terminal is to be connected to the low impedance terminal of the unknown voltage and the red HI terminal is to be connected to the high impedance terminal. A second set of terminals marked LO and GND is provided for grounding the LO input terminal to the chassis when desired. The LO terminals are connected together internally.

2-2. REAR CONTROLS AND TERMINALS.

a. FUSE. For 105-125 volt operation, the Model 660 uses a 1-ampere 3AG fuse. For 210-250 volt operation, the Model 660 uses a 0.5-ampere 3 AG fuse.

b. POWER CORD. The Model 660 is for a 105-125 volt, 50- 400 cps line source, unless otherwise specified on the rear panel. A three-wire power cord is used.

c. NULL DETECTOR OUTPUT. Two terminals, marked + and -, supply a dc signal from the null detector.

d. OUTPUT ADJUST. A screwdriver control next to the OUTPUT terminals adjusts the null detector output between 10 and 25 millivolts full scale.

2-3. PRELIMINARY PROCEDURES.

a. Connect the Model 660 power cord to a 105-125 volt, 50-400 cps line source. Set the controls as follows:

RANGE	500
NULL	VTVM
POLARITY	+
REFERENCE VOLTAGE DIALS	Zero

The decimal light between the third and fourth dials will light. Allow the instrument to warm up for 15 minutes to meet the specified accuracy on all ranges.

b. With the input terminals open, set the NULL switch on the 0.1 MV range and zero the meter with the METER ZERO control. The stability of the Model 660 is such that only one adjustment should be required in eight hours after a 15-minute warmup. Then return the NULL switch to VTVM.

2-4. OPERATING PROCEDURES.

a. The Model 660 is used as a VTVM to determine the approximate value of the unknown voltage. This value is set on the Reference Voltage Dials and the NULL switch is set at an appropriate sensitivity. Further balancing using more sensitive null ranges then determines the value of the unknown voltage to $\pm$0.02%.

b. VTVM Operating Procedures.

1. Eleven full-scale ranges are available for VTVM operation. When the NULL switch is at VTVM, the RANGE switch determines one of four full-scale ranges. By putting the five Reference Voltage Dials at zero, the Model 660 can operate as a VTVM on the seven null ranges.

2. Connect the unknown voltage to the input terminals, using the LO terminal for the low impedance terminal of the unknown.

3. Switch down to the more sensitive ranges until the meter deflection is 10% to 100% of full scale.

c. Potentiometric Operating Procedures. After determining the approximate value of the unknown voltage, determine its value to $\pm$0.02% using the potentiometric mode of the Model 660.

NOTE

Avoid large overload voltages on the null detector. No permanent damage will occur even with 500-volt overloads, but some open circuit offset will be caused in the null detector. The offset, due to the polarization of the input filter capacitors, will disappear after about an hour.

1. Leave the RANGE switch at the last setting used in the VTVM operation. If the VTVM reading is negative, reverse the POLARITY switch.

2. Set the first two Reference Voltage Dials to the first two digits of the unknown voltage found in the VTVM operation.

3. Set the NULL switch to the initial null setting shown in Table 2. Adjust the Voltage Reference Dials progressively for zero meter deflection while increasing the null detector 's sensitivity with the NULL switch. Deflections to the right indicate the voltage being measured is more positive than the Reference Voltage Dial setting.

RANGE Setting	Initial NULL Setting	Most Sensitive NULL Setting
500 volts	100 volts	10 millivolts
50 volts	10 volts	1.0 millivolt
5 volts	1 volt	0.1 millivolt
0.5 volt	100 millivolts	0.1 millivolt

TABLE 2. Recommended Null Sensitivities and Settings.

NOTE

The most accurate resistors in the Kelvin-Varley Divider are in the first two decade Reference Voltage Dials. Therefore, to obtain the most accurate readings, use the first two dials whenever possible.

4. The value of the unknown voltage is read directly from the Reference Voltage Dials. The reading of the Reference Voltage Dials is within the specified limit or error whether or not the null detector is at null if the most sensitive null range (Table 2) is used. However, when off null, the meter may be read as an approximation of the magnitude of a sixth digit.

2-5. RECORDER OUTPUT.

a. Recommended recorders for use with the Model 660 are the Moseley Autograf series 680 recorder and the Minneapolis Honeywell recorder (10mv-0-10mv scale, 50 kilohms input resistance). Any recorder used must be able to float 500 volts off ground and its input must be fully isolated (10^{10} ohm minimum leakage resistance to ground).

b. Before attaching the recorder, set all Reference Voltage Dials to zero. Disconnect the unknown voltage and short both Model 660 input terminals. Set the NULL switch to the 10 MV position. Connect the recorder to the OUTPUT terminals on the rear panel of the Model 660.

c. Set the Reference Voltage Dials to 10 millivolts to apply an accurate 10-millivolt potential to the null detector on the 10 MV null range. This will provide a full-scale recorder output which can be matched to the recorder's range between 10 and 25 millivolts by adjusting the OUTPUT ADJUST control.

d. To obtain accurate results and/or to prevent damage to the instruments, the recorder must be able to float off-ground with the Model 660. Leakage

and pickup between the two instruments should also be minimized.

1. Make sure neither recorder terminal is grounded. Use a 3-wire grounded power line for the recorder. If a 2-wire line is used, connect the recorder chassis and the Model 660 chassis with a separate lead.

2. Minimize all sources of leakage between the output terminals, the recorder and ground. Use Polystyrene or Teflon-insulated wire where possible.

3. Avoid long leads between the Model 660 and the recorder.

4. If difficulty is encountered in off-ground measurements, connect a 10 μf capacitor between the LO and GND terminals on the Model 660 front panel.

NOTE

Do not short either Model 660 output terminal to the case, as this may damage the Kelvin-Varley Divider.

e. If there is substantial recorder jitter on the 0.1 MV null range, place a filter between the Model 660 and the recorder. Refer to Figure 3 for this connection.

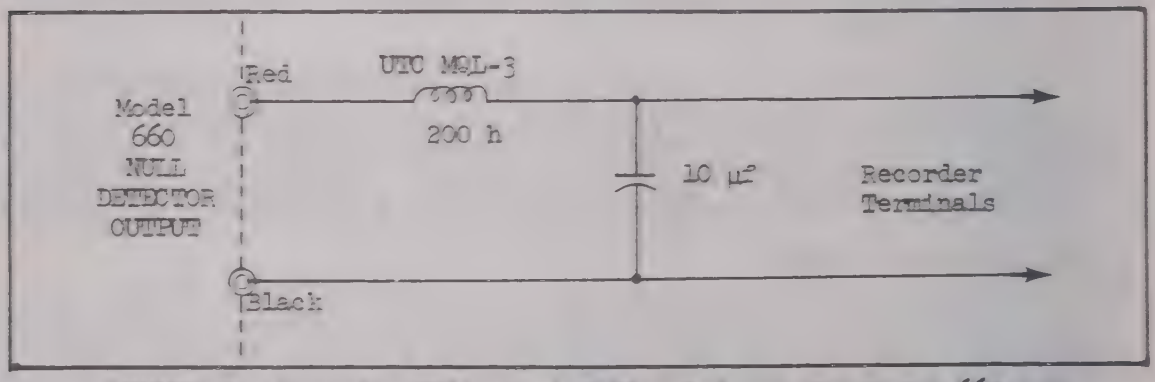


FIGURE 3. Recorder Filter. A filter between the Model 660 and the recorder may be necessary when using the 0.1-millivolt null detector range.

2-6. MEASURING RESISTANCES.

a. Procedures: The Model 660 can be used to rapidly measure resistances from 10 to 50,000 megohms with an accuracy of ±5%. To measure resistance, connect the resistor across the Model 660 HI and LO terminals. Use a short isolated lead to the HI terminal to prevent measuring leakage between the leads. Set the RANGE switch to 500. Then determine the value of the resistor as follows:

1. For resistances between 10 and 100 megohms, set the NULL switch to 10 volts; adjust the Reference Voltage Dials to obtain a full-scale meter deflection. Subtract 10.000 from the dial setting to obtain the value of the resistor in megohms.

2. For resistances between 100 and 1000 megohms, set the NULL switch to 1 volt; adjust the Reference Voltage Dials to obtain a full-scale meter deflection. Subtract 1.0000 from the dial setting and multiply the difference by ten to obtain the value of the resistor in megohms.

3. For resistances between 1,000 and 50,000 megohms, set the NULL switch to 1 volt; adjust the Reference Voltage Dials to obtain a convenient deflection on the meter. Calculate the value of the resistor using,

$$R_x = 10 \frac{E_d}{V} \text{ megohms} \qquad \text{Eq. 2-1}$$

where R_x is the unknown resistance;
E_d is the Reference Voltage Dial setting in volts:
V is the null detector meter reading in volts.

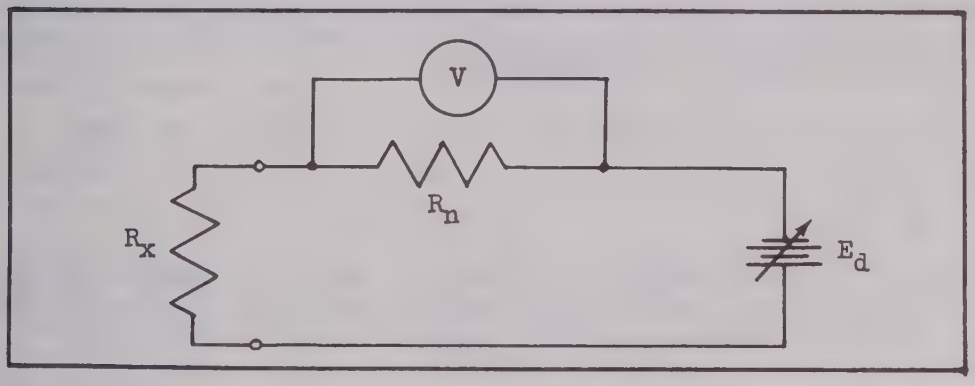


FIGURE 4. Simplified Model 660 Circuit for Measuring Resistances.

b. Theory: The above method for determining the value of an unknown resistor is based upon the equation for the circuit (see Figure 4). If an unknown resistance is across the Model 660 input terminals, then

$$E_d = i (R_x + R_n) \qquad \text{Eq. 2-2}$$

where E_d is the Reference Voltage Dial setting in volts;
i is the current in the circuit;
R_x is the unknown resistance;
R_n is the input resistance of the null detector meter in ohms;

The current can be written $i = V/R_n$.
where V is the null detector meter reading in volts.
Equation 2-2 now becomes

$$R_x = R_n \left(\frac{E_d}{V}\right) - R_n \qquad \text{Eq. 2-3}$$

If measurements are made on the 1 to 100-volt null ranges, the input resistance, R_n, is 10 megohms.
Equation 2-3 becomes

$$R_x = 10^7 \left(\frac{E_d}{V}\right) - 1 \qquad \text{Eq. 2-4}$$

2-7. EFFECTS DUE TO KELVIN-VARLEY OUTPUT RESISTANCE.

a. When the Model 660 is used for nulling on the 0.1 MV range, the last Reference Voltage Dial may appear to be inaccurate. The apparent error is due to a voltage drop across the Kelvin-Varley Divider. This effect involves only the null detector sensitivity and not the accuracy of the dial setting. When the Model 660 is as near to null as possible, the Reference Voltage Dial setting is correct within the instrument's specifications.

b. The effect is most apparent on the 0.1 MV null range. A 0.1 millivolt off-null setting of the reference voltage will not produce a full-scale deflection on the meter. The output resistance of the Kelvin-Varley Divider is significant compared to the shunt resistance across the null detector meter, and the IR drop across the Divider will cause the meter to be in error from 1% to 38%. On the 100, 10 and 1 MV null ranges, a setting of 100, 10 and 1 millivolt off-null respectively, can show up as an error of up to 6% for Reference Voltage Dial settings near 25000. The effect cannot be observed on the other null ranges of the Model 660.

c. The amount of deflection on the meter is equal to the ratio

$$\frac{R_n}{R_n + R_{kv}}$$

where R_n is the shunt resistance across the meter (10 megohms for the 100 to 1-volt null ranges, 1 megohm for the 100 to 1-millivolt null ranges, and 100 kilohms for the 0.1-millivolt null range);

R_{kv} is the output resistance of the Kelvin-Varley Divider, which is a maximum of 62.4 kilohms at settings of 24545 and 25455 and a minimum of 100 ohms at settings of 49998 and 00002.

d. The input resistance on the 0.1 MV range may be increased by substituting a 1 megohm, $\frac{1}{2}$ watt resistor for the 100-kilohm input resistor, R1003, if the source resistance is not more than 100 kilohms. The higher input resistor will increase the input noise of the instrument open circuited only. The effect of line transients will also be more apparent.

2-8. LOADING AND OFF-NULL RESISTANCE.

a. The input resistance of the voltmeter for the seven null ranges varies from 10 megohms to 100 kilohms as given in the Specifications. This resistance, however, is not the input resistance of the Model 660. Its input resistance is considerably higher due to the potentiometric principle of operation. The value is given by

$$R_{in} = \frac{E_d R_n}{V} \qquad \text{Eq. 2-5}$$

where R_{in} is the input resistance of the Model 660;
E_d is the voltage indicated on the Reference Voltage Dials;
R_n is the shunt resistance or input resistance of the null detector meter;
V is the null detector meter reading.

b. To find the loading effect the Model 660 will have on a circuit, equation 2-5 may be used to compute the input resistance of the instrument. At null, the input resistance is infinite. Off null, the input resistance is usually high compared to the internal resistance of the unknown voltage, and the loading will not be enough to affect the accuracy of the measurement. For example, the Model 660 input resistance is 10^{10} ohms if the Reference Voltage Dials are set at 1.0000 volt on the 1 MV null range for a reading off null by 10% of full scale.

2-9. THERMAL EMF PRECAUTIONS. Observe standard thermocouple techniques to reduce thermal emf errors for measurements using the most sensitive null ranges. Since the Model 660 can read to 0.5 microvolt, thermal emf's can introduce considerable errors into the measurements. In general, use pure copper leads throughout the system when measuring in the microvolt range.

2-10. AC EFFECTS ON MEASUREMENTS. To minimize errors from ac signals present in the unknown voltage, the Model 660 employs a chopper-stabilized null detector operating at a 42 cps chopping rate with a two-section R-C filter at the input. Very large ac components on the measuring lines, however, may reduce off-null sensitivity. Also, heavy 60-cps pickup will be observed as needle quiver. If ac components affect measurements by the Model 660, additional filtering is required. For an ac signal of a single frequency, a twin T filter is effective. For an ac variable frequency, an ordinary low pass filter may be used.

2-11. PREPARATION FOR RACK MOUNTING. (See Figure 5.)

a. The Model 660 is shipped for bench use with four feet and a tilt-bail. The Model 4000 Rack Mounting Kit converts the instrument to rack mounting to the standard EIA (RETMA) 19-inch width.

Item (See Figure 5)	Description	Keithley Part No.	Quantity
1	Cover Assembly	14623B	1
2	Cover Assembly, Bottom (Supplied with Model 660)	14590B	1
3	Angle, Rack	14624B	2
4	Screw, Phillips Head, 10-32 UNC-2x$\frac{1}{4}$ (Supplied with Model 660)	---	4
5	Front Panel (Supplied with Model 660)	---	1

TABLE 3. Parts List for Model 4000 Rack Mounting Kit.

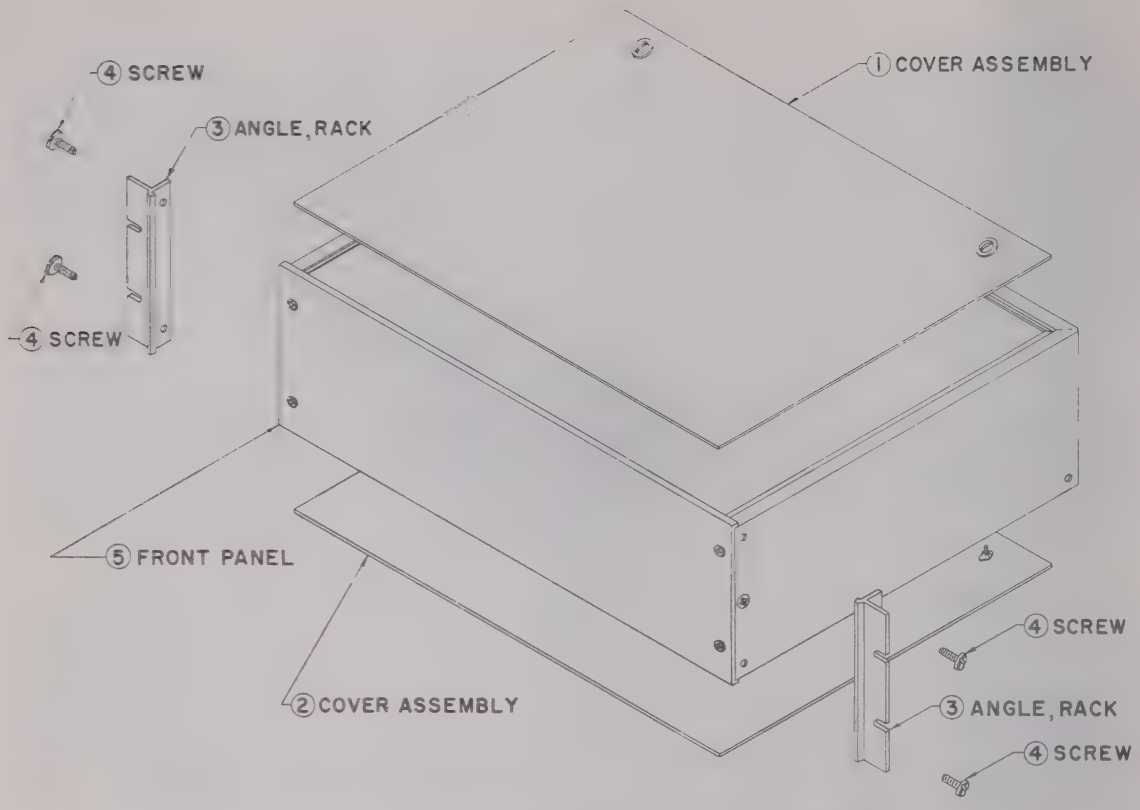


FIGURE 5. Exploded View for Rack Mounting.

b. To convert the Model 660, remove the four Phillips head screws at the bottom of each side of the instrument case. Lift off the top cover assembly with the handles; save the four screws. To remove the feet and tilt bail from the bottom cover assembly, turn the two screws near the back. The two pawl-type fasteners will release the cover and allow it to drop off. Remove the feet and the tilt bail and replace the cover (2).

c. Attach the pair of rack angles (3) to the cabinet with the four Phillips head screws (4) previously removed. Insert the top cover assembly (1) in place and fasten to the chassis with the two pawl-type fasteners at the rear. Store the top cover with handles, feet and tilt-bail for future use.

2-12. PLACING IN RACK. The Model 660, once converted for rack mounting, easily fits into the rack. It is recommended, however, that a blower be used in the rack enclosure in which the Model 660 is mounted. The instrument specifications state a 0.002% per °C temperature coefficient. A temperature rise of 5 °C (9 °F) will cause a 0.01% error.

SECTION 3. CIRCUIT DESCRIPTION

3-1. GENERAL. The Model 660 consists principally of a reference power supply, a Kelvin-Varley Divider and a null detector (see Figure 6). The Kelvin-Varley divider precisely divides a stable, accurate 500-volt potential from the reference power supply. The divided reference voltage is compared to an unknown voltage. Differences between the internal and the unknown voltages are measured by the null detector. Null is achieved by adjusting the Kelvin-Varley Divider. The voltage required for null is read directly from the five Reference Voltage Dials.

NOTE

The circuit designations referred to in the following paragraphs are for the schematic diagram 15199H found at the back of this manual.

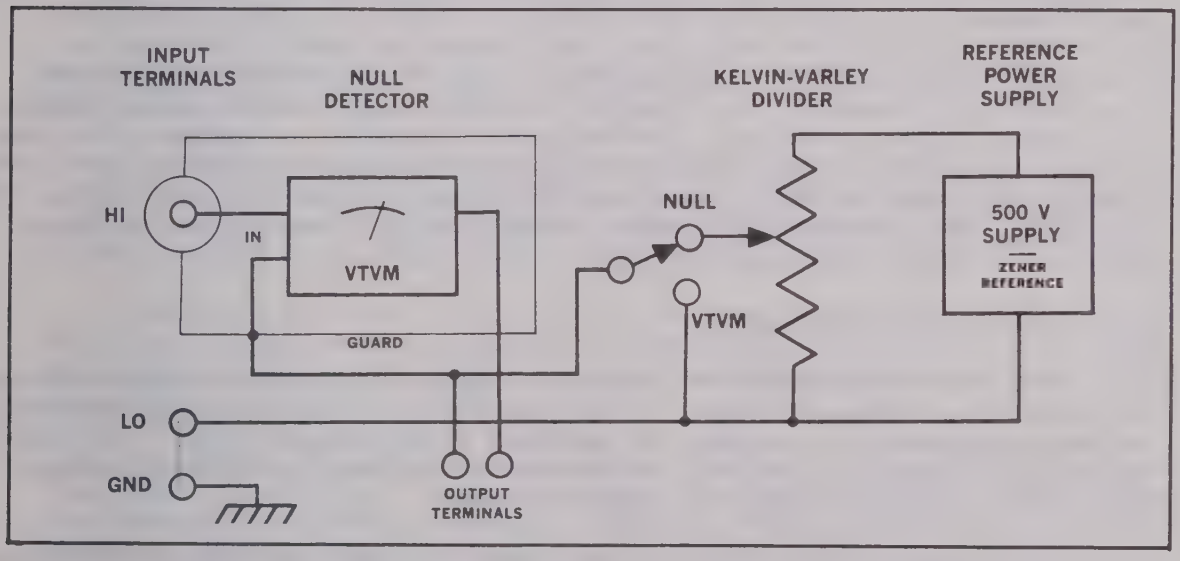


FIGURE 6. Simplified Circuit Diagram of the Model 660.

3-2. REFERENCE POWER SUPPLY.

a. Unregulated voltage from the transformer T3001 is rectified by a silicon half-wave rectifier, D3004, and is filtered by capacitors C3003, C3004 and C3005. The voltage then is applied to the preregulator series pass tube, V3005.

b. The output voltage of V3005 is regulated by comparing a sample voltage from divider string, R3015, R3016 and R3017, to the reference, regulator tube V3007. The difference between the two potentials is amplified by V3006. The amplifier output drives the grid of V3005 in the proper phase to nullify input variations. The ac feedback loop, containing capacitor C3007, is used for better high frequency and transient response.

c. The regulated output of V3005, is applied to the second series tube, V3004, for final regulation. To obtain a stable, accurate voltage, the 500-volt output of V3004 is sampled by a divider network of wirewound resistors, R3034, R3036, R3037, R3049 and R3050. The divider network ratio is adjusted with potentiometer R3035 to better than 0.01%. Light modulator E3002 compares the sample voltage from the divider network to the voltage across the ultra-stable zener diode, D3009. If there is a difference between the sampled voltage and the voltage of D3009, it is chopped by E3002 and amplified by a two-stage ac coupled amplifier, V3001. The amplified output of V3001 is converted to a dc signal by light modulator, E3001, and then is amplified by the two-stage differential dc amplifier, V3002 and V3003. The amplifier output is applied to the grid of the series tube, V3004, in the proper phase to nullify input variations. Capacitor C3009 is used in the ac feedback circuit.

d. The temperature-compensated zener diode was used as the circuit's basic reference since typical variations are limited to less than 20 ppm per year and 5 ppm per °C. Thus, a highly stable reference is provided with respect to both time and temperature. The zener diode will also withstand extreme shock and vibration.

e. The regulated 500 volts from V3004 either is applied directly to the Kelvin-Varley Divider or it is divided to 50, 5, or 0.5 volts by very stable wire-wound resistor networks. The Range switch, S3002, determines which network is used. The 50-volt range divider network consists of R3040, R3041 and R3042; the 5-volt, of R3040, R3044 and R3045; and the 0.5-volt, of R3040, R3047 and R3048. The potentiometers R3041, R3044 and R3047 are used to accurately set the voltage division on each range.

3-3. KELVIN-VARLEY DIVIDER.

a. The Kelvin-Varley Divider precisely divides the reference supply voltage for nulling an unknown voltage. It is, in effect, a constant input impedance decade potentiometer consisting of resistors R3051 through R3099. The resistors within each decade are matched; the decades are matched for each instrument. The overall divider accuracy is 0.01% absolute.

b. Each decade of the Kelvin-Varley Divider, except the first, R3051 through R3056, parallels two resistors of the preceeding string. Between the two contacts of the first Reference Voltage switch, S3003, the total resistance is 40 kilohms, i.e., 80 kilohms in parallel with the 80 kilohms total resistance of the four remaining strings. With the Range switch set at 500, 100 volts dc will appear across the contacts of the next three Reference Voltage switches, S3004, S3005 and S3006. The last Reference Voltage switch, S3007, determines increments of 0.01 volts. The potentials across the Reference Voltage switch contacts are reduced in 0.1 steps for each lower voltage range.

3-4. NULL DETECTOR.

a. The Model 660 uses a null detector with a chopper stabilized, feedback amplifier. The input signal is attenuated, if necessary, and sent through a two-stage R-C filter. The signal is then amplified and measured by the null detector meter.

b. The null detector has basically three full-scale sensitivities, 0.1, 1 and 10 millivolts. Above the 10-mv range, the input is divided by resistor R1002 through R1007 to the 10-mv level. The full-scale sensitivities are determined by which of three feedback resistors, R1037, R1038 or R1039, is in the circuit. A two-stage R-C filter, consisting of R1008, C1001, R1009 and C1002, is used to decrease the ac input components. The input filter attenuation ratio is 35db at 60 cps. The light modulators are driven by a 42-cps multi-vibrator. Using a drive source harmonically unrelated to the standard line frequency minimizes 60-cps pickup effects.

c. The light modulators E1001 and E1002 convert the difference between the filtered input voltage and the output of the Kelvin-Varley Divider into an ac voltage, which is fed to a four-stage ac coupled amplifier, V1001 and V1002. The output of the amplifier is then demodulated by light modulator E1003 and applied to an R-C filter, R1034 and C1017. The null detector meter, M1001, indicates the value of the filtered signal.

d. One arm of the feedback network is formed by resistors R1043, R1040, R1041, R1042 and one of the feedback range resistors, R1037, R1038 or R1039. Resistor R1036 forms the second shunt arm. The feedback is applied to light modulator E1002. The low end of C1001 is also returned to the feedback point for faster speed of response.

e. A zero-control network is across resistor R1009 to buck out thermal emf's at the input on the two most sensitive ranges. The network consists of a 1.32-volt mercury battery, BT1001, and resistors R1010 through R1013. The zero control on the front panel, R1013, has approximately a 100-microvolt span.

f. The null detector output is obtained across resistors R1040 and R1043, which are in the feedback network. Potentiometer R1043 adjusts the output from 10 to 25 millivolts at full scale. The output voltage is proportional to the full scale meter reading.

3-5. GUARDING. Guarding is accomplished by floating the null detector and the input circuitry at a voltage equal to the input voltage from a low impedance source. This full guarding eliminates leakage between the input terminal and ground. Such leakage in an unguarded circuit is difficult to avoid, even under laboratory conditions, and can result in sizeable errors. For example, in an unguarded circuit with a 1-megohm source, leakage of 10^8 ohms will introduce 0.1% error. A guarded circuit eliminates this element of error. The effectiveness of guarding in the Model 660 is demonstrated by setting the null detector on the 0.1-mv range, with the input circuit open, and the Reference Voltage Dials set to 500 volts. Even at this extreme condition there is no deflection on the meter, demonstrating there is no leakage.

SECTION 4. MAINTENANCE

4-1. GENERAL.

a. Section 4 contains the maintenance, troubleshooting and calibration procedures for the Model 660. It is recommended that these procedures be followed as closely as possible to maintain the accuracy and stability of the instrument.

b. The Model 660 needs no periodic maintenance beyond the normal care required of high-quality electronic equipment.

4-2. TROUBLESHOOTING.

a. The procedures which follow give instructions for repairing troubles which might occur in the Model 660. Use the procedures outlined and use only specified replacement parts. Table 4 lists equipment needed for troubleshooting. If the trouble cannot be readily located or repaired, Keithley Instruments will gladly service the instrument at its complete service facilities. Refer to the page at the back of the Manual for shipping instructions.

b. Paragraph 2-11 describes how to remove the Model 660 cover. Before proceeding with the troubleshooting, check the vacuum tubes in the instrument. Normally, replacing tubes will clear up the difficulty. All tubes can be readily tested on a grid-modulated tube tester. If replacing a tube does not correct the trouble, continue the procedures. Replacing tubes does not necessitate recalibration of the instrument.

c. Table 5 contains the more common troubles which might occur with the instrument. If the repairs indicated in the table do not clear up the trouble, the difficulty will have to be found through a point-by-point check of the circuits. Refer to the circuit description in Section 3 to find the more crucial components and to determine their function in the circuit. The complete circuit schematic, diagram 15199H, is found in Section 5.

Instrument	Use
Keithley Model 610A Electrometer	Voltmeter, Ohmmeter
Keithley Model 503 Milliohmmeter	Ohmmeter for resistors less than 1 kΩ
Grid-modulated tube tester	
Keithley Model 660 Differential Voltmeter	Test Kelvin-Varley Divider resistors.

TABLE 4. Equipment Needed for Troubleshooting Model 660.

4-3. PARTS REPLACEMENT. The Replaceable Parts List in Section 5 describes the electrical components in the Model 660. Replace components only as necessary. Use only reliable replacements which meet the specifications. It is recommended that the resistors in the Kelvin-Varley Divider, switches S3004 through S3007, be replaced only by Keithley Instruments because of the matching involved.

Difficulty	Probable Cause	Solution
Poor null meter sensitivity on millivolt ranges.	C1018 or R1046 out of adjustment.	Adjust per paragraph 4-4.
Needle quiver	R1046 is out of adjustment.	Adjust per paragraph 4-4.
Meter rattle, drift or error is observed on all null ranges.	Tube V1001, V1002 or V2001 is faulty.	Check tubes and replace if faulty.
Variations in line voltages cause Model 660 measurements to be out of specifications.	Tube V3005, V3006 or V3007 is defective.	Check tube and replace if faulty.
The reference supply drifts, requiring frequent adjusting of the range controls, R3035, R3041, R3044, R3047.	V3001, V3002, V3003 or V3007 is defective.	Check tubes and replace if faulty.
	One of the divider resistors, R3034 through R3037, R3049 and R3050, is changing value rapidly during warmup.	Test the resistors and replace any faulty components.
	Zener reference diode, D3009, is unstable.	Check zener diode per paragraph 4-5. Replace if faulty.
	Light modulator E3002 is defective.	Check light modulator by replacing.
Measurements are out of tolerance on the 500-volt range.	Out of calibration.	Refer to paragraph 4-7 for recalibration.
	One of the divider resistors is faulty.	Check stability for 24 hours. If 500-volt reference supply remains stable, replacement of resistors is not needed.
	Noisy or unstable zener reference diode, D3009.	Check zener diode. Replace if faulty.

TABLE 5 (Sheet 1). Troubleshooting.

Measurements are out of specifications on one range other than 500-volt range.	A resistor in the range divider network is faulty.	Paragraph 3-2, subparagraph e, points out the resistors used for each range. Try to bring the ranges within specification by calibrating with the potentiometers in the network. If it does not work, check individual resistors.
Measurements are out of specifications on all ranges other than 500-volt range.	Resistor R3040 is faulty.	Replace the faulty resistor.
Measurements are out of specifications on any range when the Kelvin-Varley Divider is dialed to any setting other than 499910.	One of the Kelvin-Varley Divider resistors is faulty.	Measure the voltage drop across each Kelvin-Varley resistor with another Model 660 Differential Voltmeter. Begin by setting the RANGE switch to 500 volts and the Reference Voltage Dials to 499.910. There should be 100, 10, 1, 0.1 and 0.01 volts respectively across each resistor of the five decade switches, except the two resistors in each decade which are paralleled by the following decade. Across these two resistors, there should be 50, 5, 0.5 and 0.05 volts respectively. Measure all voltage ±0.02%. Remember that if one resistor in a decade has increased or decreased appreciably, the voltage drop across all other resistors in the decade will be slightly affected also.
Instrument is out of specifications on all ranges.	One of resistors R1001 through R1007 is faulty.	Check and replace faulty resistor.

TABLE 5. (Sheet 2). Troubleshooting

4-4. ADJUSTMENT OF HUM BUCKING CONTROLS.

a. Adjusting Trimmer C1018.

1. A capacitor trimmer, C1018, is provided to null out residual ac components in the transformer, T3001. If this adjustment is not properly set, decreased null sensitivity will occur. On the 0.1 MV null range, however, it is normal to have a sensitivity of 62% of full scale when the Reference Voltage Dials are set near 25000, due to the loading of the null detector input impedance by the Kelvin-Varley Divider.

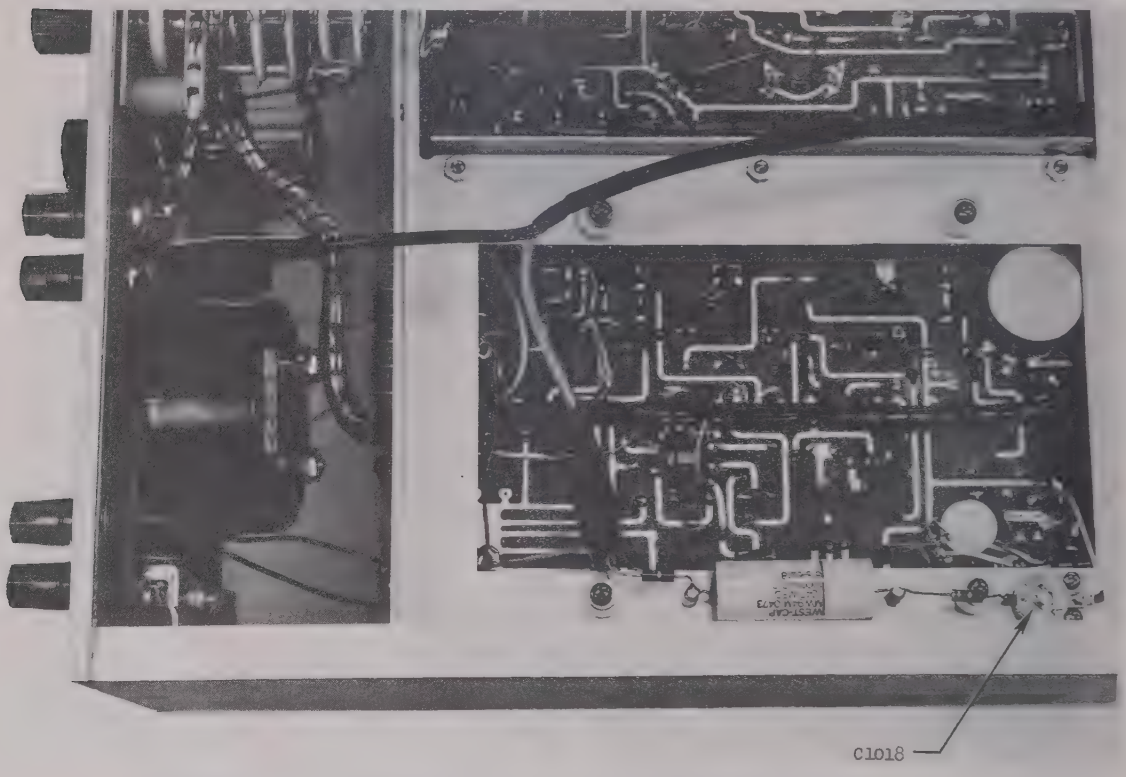


FIGURE 7. Attaching Oscilloscope Leads for Adjusting Trimmer. The oscilloscope is attached to the LO input terminal and the Guard Circuit.

2. To adjust the trimmer, remove the bottom cover and attach an oscilloscope between the LO input terminal and the guard circuit (see Figure 7). With the Reference Voltage Dials set for either 24545 or 25455, the wave form should be similar to that shown in Figure 8. Adjust trimmer C1018 until the wave form is correct.

b. Adjusting Potentiometer R1046

1. An adjustment, potentiometer R1046, is provided to minimize 60 cps pickup in the null detector. Misadjustment will cause reduced sensitivity and needle quiver.

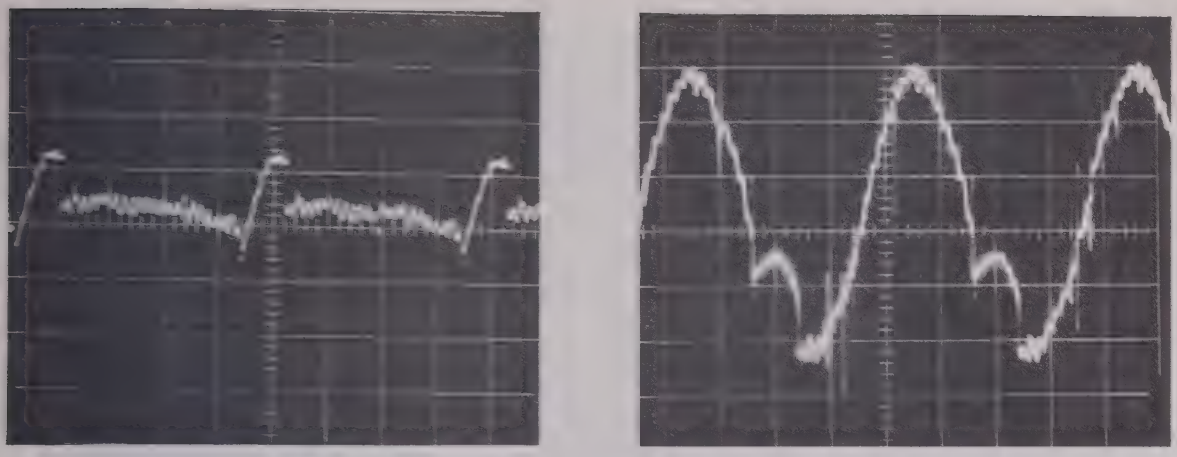


FIGURE 8. Waveforms for Adjusting Trimmer. The waveform with C1018 properly adjusted is shown in (a). The waveform with a misadjusted trimmer is shown in (b). A Tektronix 503 Oscilloscope was used; horizontal sweep was 20 msec/cm; vertical, 10 mv/cm.

2. To adjust the potentiometer, set the Reference Voltage Dials to zero and short the input terminals. Attach an oscilloscope to the plate of V1002 (pin 6). Figure 9 shows the waveform if potentiometer R1046 is adjusted for minimum output.

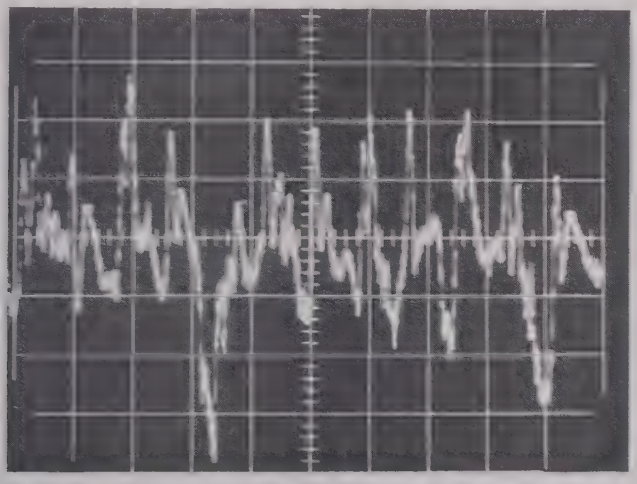


FIGURE 9. Waveform with R1046 Adjusted. A Tektronix 503 Oscilloscope was used; horizontal sweep was 20 msec/cm; vertical , 100 mv/division.

4-5. ZENER CURRENT TEST. When the reference power supply is operating properly, the zener current will be 7.5 milliamperes and the voltage across R3031 should be ~~75~~ 750 millivolts.

4-6. CALIBRATION PROCEDURES.

a. The following procedures are recommended for calibrating the Model 660. It is also recommended that the equipment listed in Table 6 be used. If proper facilities are not available or if difficulty is encountered, Keithley Instruments can recalibrate the instrument. Please refer to the back of the Manual for shipping instructions.

b. Two procedures are covered here; the calibration of the voltage ranges and the test of the reference power supply stability.

c. The Troubleshooting Table (Table 5) contains testing procedures for the Kelvin-Varley Divider. There is no in-field calibration, however. Specifications concerning the divider are dependent upon matching resistors and switches. The accuracy of the Kelvin-Varley Divider is initially established by matching each resistor within the first two Reference Voltage switches -- S3003 and S3004 -- to 0.005%. The resistors in each of the first two switches are checked as a set to an accuracy of better than 0.01%. All parts replacement and testing of these resistors and switches should be done by Keithley Instruments.

d. If the instrument is not within specifications after performing the calibration procedures, please return the unit to Keithley Instruments for further check-out.

Instrument	Use
Electro Scientific Industries Model CA-1255 Voltage Calibrator.	Voltage Calibrator
Electro Scientific Industries Model RV-722 Kelvin-Varley Divider.	Voltage Divider
Keithley Instruments Model 151 Microvoltmeter	Null Detector
Keithley Instruments Model 241 Regulated High Voltage Supply	Power Supply
Mosley Instruments Model 680 Direct Reading Recorder	Recorder
Weston Instruments Model 3 Type 7 Saturated Standard Cell	Standard
Weston Instruments Model 66 Oil Bath	Oil Bath

TABLE 6. Equipment Used in Calibration of Model 660.

4-7. RANGE CALIBRATION.

a. The reference power supply has a 500-volt output which can be attenuated to 50, 5 or 0.5 volts. This output voltage is then divided by the Kelvin-Varley Divider to provide the accurate buckout voltage. Each of the four voltage ranges is set by internally adjusting potentiometers R3035, R3041, R3044 and R3047.

b. Range calibration most quickly brings the Model 660 within its specifications. If the instrument requires frequent calibration, test the reference power supply stability (paragraph 4-8). If the output voltages cannot be calibrated, locate the trouble through the troubleshooting procedures. After making the repair, calibrate the range output voltages.

c. For the calibration, an accurate potential is applied to the Model 660 for each setting of the RANGE switch. The Model 660 is set to furnish an equivalent buckout voltage, and the internal range potentiometer is adjusted until the Model 660 indicates a null. As shown in Figure 10, the potential applied to the Model 660 is from the Keithley Model 241 Regulated High Voltage Supply, accurate to ±0.05% and stable to 0.005% per hour. The ESI Model CA1255 Voltage Calibrator, accurate to ±0.005%, divides the voltage for the Model 660 range under adjustment. The Voltage Calibrator is standardized with a Weston Model 3 Type 7 saturated standard cell, accurate to 0.001%, and a Keithley Model 151 Microvoltmeter. The Model 151 serves as a null detector, with resolution to ±2 microvolts, between the divider voltage and the standard cell. Using this circuit, the accuracy of the calibration voltage furnished to the Model 660 is between -0.004% and +0.006%.

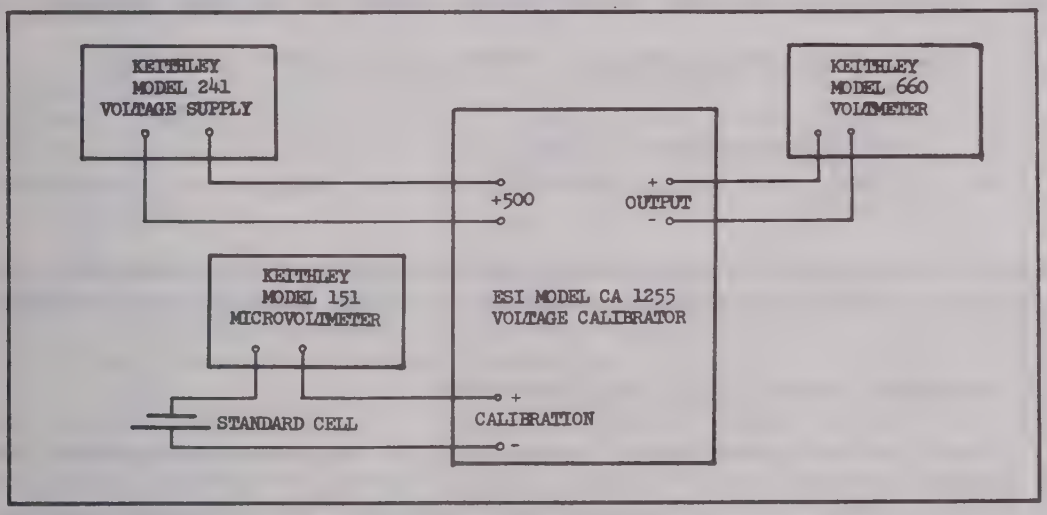


FIGURE 10. Model 660 Range Calibration Diagram.

d. Procedures for Range Calibration.

1. 500-Volt Range Calibration. Set the Model 660 as follows:

RANGE:	500
REFERENCE VOLTAGE:	499.910
NULL:	VTVM
POLARITY:	+

Adjust the Voltage Calibrator to apply 500 volts dc to the Model 660. Turn the Model 660 Null switch to 10 MV and adjust the 500 V CALIBRATE potentiometer R3035 for null on the Model 660.

2. 50-Volt Range Calibration. Set the Model 660 as follows:

RANGE:	50
REFERENCE VOLTAGE:	49.9910
NULL:	10 MV
POLARITY:	+

Adjust the Voltage Calibrator to apply 50 volts dc to the Model 660. Adjust the 50 VOLT CALIBRATION potentiometer R3041 for null on the Model 660.

3. 5-Volt Range Calibration: Set the Model 660 as follows:

RANGE:	5
REFERENCE VOLTAGE:	4.99910
NULL:	1 MV
POLARITY:	+

Adjust the Voltage Calibrator to apply 5 volts dc to the Model 660. Adjust the 5 VOLT CALIBRATION potentiometer R3044 for null on the Model 660.

4. 0.5-Volt Range Calibration: Set the Model 660 as follows:

RANGE:	0.5
REFERENCE VOLTAGE:	.499910
NULL:	0.1 MV
POLARITY:	+

Adjust the Voltage Calibrator to apply 0.5 volt dc to the Model 660. Adjust the 0.5 VOLT CALIBRATION potentiometer R3047 for null on the Model 660.

4-8. REFERENCE POWER SUPPLY STABILITY TEST.

a. The reference power supply, consisting of the power transformer, the main supply (printed circuit PC 55), and the reference section (printed circuit PC 61), is factory calibrated for an output of 500 volts dc ±0.005%. Its stability is ±0.005% indefinitely after a one-hour warmup. The 500-volt output is adjustable to meet specifications. If the stability of the reference power supply is not within specifications, then troubleshooting for a faulty component or replacing the power supply is probably required.

b. Routine calibration of the Model 660 does not require a stability test of the reference power supply. However, a stability test is recommended if one of the components in the reference power supply is replaced.

c. For the test, the reference power supply is compared to a standard cell for 24 hours. The 500-volt output is divided and then compared to a 1.02-volt saturated standard cell using a sensitive null detector, the Keithley Model 151 Microvoltmeter. Any variation between the reference power supply and the standard cell is detected by the Model 151 and is recorded on a recorder. Refer to Figure 11 for the block diagram of the test circuit.

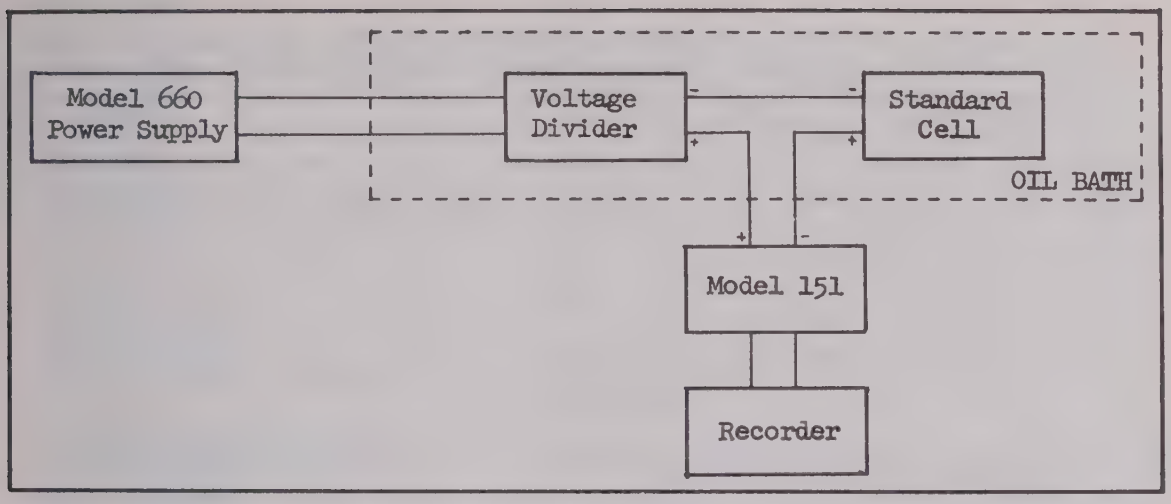


FIGURE 11. Circuit Diagram for Reference Power Supply Stability Test.

d. In using the test circuit, the following points are important.

1. Saturated standard cells, though extremely stable with time, have a high temperature coefficient and require a controlled environment during use. Therefore, the Weston Oil Bath, which is maintained at +35°C ±0.05°C, is used for the test. Unsaturated standard cells have a lower temperature coefficient, but they do not have the long stability required for this test.

2. The resistor divider network is constructed from wire of the same spool for an extremely close temperature coefficient match (4 ppm, typically). Additional stability results when the resistors are immersed in an oil bath to hold the ambient temperature variations to ±0.05°C. The ratio accuracy of the network can be within ±0.01%, since the Model 660 has potentiometer R3035 to compensate for minor voltage variations when the reference power supply is compared to the standard cell.

e. Procedures for the Reference Power Supply Stability Test.

1. After the saturated standard cell and the resistor divider network are placed in the oil bath and connected to the circuit, allow sufficient time for the cell to stabilize at +35°C. (Consult Keithley Instruments for details.) Set the Model 660 controls as follows:

RANGE:	500
REFERENCE VOLTAGE:	499.910
NULL:	10 MV
POLARITY:	OFF

Connect the resistor divider network across the Model 660's reference power supply, the positive side of the divider input to the wiper arm of the last Reference Voltage Switch, S3007, and the negative side of the divider to the LO terminal on the Model 660 front panel.

2. Connect the Model 151 and the recorder as shown in Figure 11. Set the Model 151 to the 3-volt range. Advance the Model 660 POLARITY switch to + to put 500 volts across the divider. If the Model 151 reads two volts, the standard cell and the divider voltages are improperly connected in series. If the circuit is correct, the Model 151 will read zero. Increase the Model 151's sensitivity to the 0.1-millivolt range. If it reads more than 20 microvolts, adjust the 500 V CALIBRATE potentiometer, R3035, for a null.

NOTE

If potentiometer R3035 is adjusted, the other ranges must also be calibrated. See paragraph 4-7.

3. After a one-hour warmup, the drift of the entire system should not exceed ±50 microvolts in 24 hours.

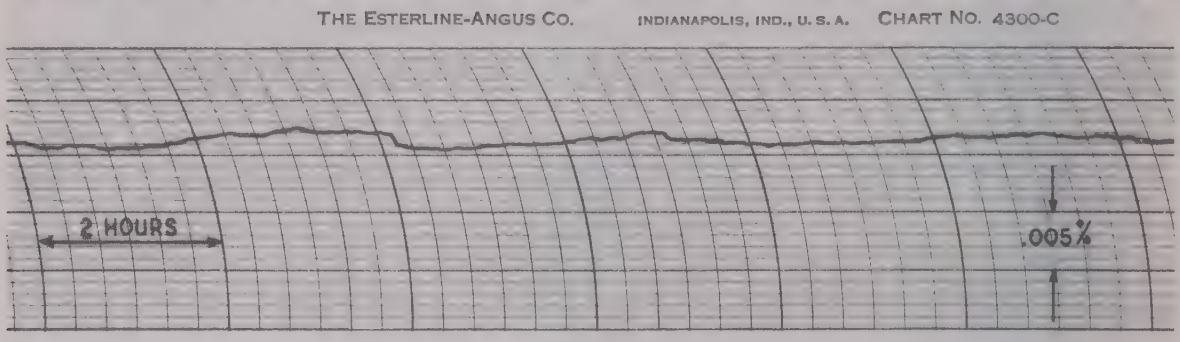


FIGURE 12. Stability Strip Chart for Model 660 Reference Power Supply. The chart covers about a 15-hour period. Each major division represents 0.005% change. Above sample was taken after a one-hour warmup. No effort was made to compensate for variations of line voltage or ambient temperatures.

SECTION 5. REPLACEABLE PARTS

5-1. REPLACEABLE PARTS LIST.

a. The Replaceable Parts List describes the components of the Model 660 Guarded DC Differential Voltmeter and its accessories. The List gives the circuit designation, the part description, a suggested manufacturer and the Keithley Part Number. The name and address of the manufacturers listed in the "Mfg. Code" column is contained in Table 8.

b. In some instances, it is necessary to substitute parts in the instrument you receive. These substitutions do not impair the performance of the instrument. Either the substitute part or the part specified in the Replaceable Parts List may be used for replaceament purposes.

5-2. HOW TO ORDER PARTS.

a. For parts orders, include the instrument's model and serial numbers, the Keithley Part Number, the circuit designation and a description of the part. All structural parts and those parts coded for Keithley manufacture (80164) must be ordered from Keithley Instruments, Inc. In ordering a part not listed in the Replaceable Parts List, completely describe the part, its function and its location.

b. If any part ordered has been replaced by a new or improved part, the new part will be shipped.

c. Order parts through:

Sales Service Department
Keithley Instruments, Inc.
12415 Euclid Avenue
Cleveland, Ohio 44106
Telephone 795-2666, Area Code 216

amp	ampere	Mil No.	Military Type Number
		μ	micro (10^{-6})
CbVar	Carbon Variable	MtF	Metal Film
CerD	Ceramic, Disc	My	Mylar
Coml	Commercial		
Comp	Composition	Ω	ohm
EMC	Electrolytic, metal cased	Poly	Polystyrene
ETT	Electrolytic, tantalum		
		v	volt
f	farad	Var	Variable
k	kilo (10^3)	w	watt
		WW	Wirewound
M or meg	mega (10^6) or megohms	WWVar	Wirewound Variable
m	milli (10^{-3})		
Mfg	Manufacturer		

TABLE 7. Abbreviations and Symbols.

MODEL 660 REPLACEABLE PARTS LIST

(Refer to Schematic Diagram 15199H for circuit designations)

CAPACITORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.
C1001	1.0 µf	600 v	MtF	13050	C12-1.0
C1002	1.0 µf	600 v	MtF	13050	C12-1.0
C1003	.05 µf	600 v	My	56289	C62-.05
C1004	80 µf	350 v	EMC	53021	C32-80
C1005	200 µf	3 v	EMC	14655	C48-200
C1006	10 µf	15 v	EMC	56289	C3-10
C1007	.1 µf	600 v	MtF	02777	C47-0.1M
C1008	.05 µf	600 v	My	56289	C62-.05
C1009	40/20 µf	450 v	EMC	56289	C36-40/20
C1010	.047 µf	1000 v	Poly	96733	C67-.047
C1011	.002 µf	600 v	CerD	72982	C22-.002
C1012	10 µf	15 v	EMC	56289	C3-10
C1013	.1 µf	600 v	MtF	02777	C47-0.1M
C1014	.25 µf	400 v	MtF	13050	C73-.25
C1015	100 µf	15 v	EMC	56289	C3-100
C1016	4 µf	250 v	EMC	56289	C27-4
C1017	560 µf	6 v	ETT	12065	C95-560
C1018	4.5/25 pf	500 v	Trimmer	71590	C76-4.5/25P
C2001	Not Used				
C2002	.022 µf	400 v	MtF	13050	C73-.022
C2003	.022 µf	400 v	MtF	13050	C73-.022
C3001	.001 µf	600 v	CerD	72982	C22-.001
C3002	1000 µf	15 v	EMC	56289	C4-1000
C3003	20 µf	450 v	EMC	37942	C36-20
C3004	20 µf	450 v	EMC	37942	C36-20
C3005	20/40 µf	450 v	EMC	56289	C36-40/20
C3006	330 pf	600 v	CerD	72982	C22-330P
C3007	.01 µf	2000 v	CerD	56289	C88-.01
C3008	.01 µf	600 v	CerD	01121	C22-.01
C3009	1.0 µf	1000 v	MtF	13050	C14-1.0
C3010	.05 µf	600 v	My	56289	C62-.05
C3011	4 µf	250 v	EMC	56289	C27-4
C3012	50 µf	6 v	EMC	56289	C17-50
C3013	.0047 µf	600 v	CerD	01121	C22-.0047
C3014	.022 µf	200 v	MtF	13050	C6-.022
C3015	.05 µf	1600 v	My	14655	C87-.05

DIODES

Circuit Desig.	Type	Number	Mfg. Code	Keithley Part No.
D1001	Not Used			
D1002	Not Used			
D1003	Silicon	1N482	81453	RF-14
D1004	Silicon	1N482	81453	RF-14
D3001	Silicon	1N3256	02735	RF-22
D3002	Not Used			
D3003	Not Used			
D3004	Silicon	1N2378	08520	RF-25
D3005	Silicon	1N3256	02735	RF-22
D3006	Silicon	1N1563A	04713	RF-19
D3007	Silicon	1N1563A	04713	RF-19
D3008	Zener	R1302	99942	DZ-9
D3009	Zener	69-2595	81483	DZ-10

MISCELLANEOUS PARTS

Circuit Desig.	Description	Mfg. Code	Keithley Part No.
BT1001	Battery, 1.32-volt Mercury (Mfg No PX13T2)	37942	BA-12
DS2001	Neon Pilot Light (Mfg No. NE-2P)	08804	PL-2
DS2002	Neon Pilot Light (Mfg No. NE-2P)	08804	PL-2
DS2003	Neon Pilot Light (Mfg No. NE-2P)	08804	PL-2
DS2004	Neon Pilot Light (Mfg No. NE-2P)	08804	PL-2
E1001	Light Modulator	80164	1510
E1002	Light Modulator	80164	1510
E1003	Light Modulator	80164	1511
E3001	Light Modulator	80164	1510
E3002	Light Modulator	80164	1510
F1001 (117v)	Fuse, 1.0 amp, 3 AG	75915	FU-10
F1001 (234v)	Fuse, 0.5 amp, 3 AG	75915	FU-6
---	Fuse Holder	75915	FH-3
J1001	Binding Post, HI (Mfg No. DF31RC)	58474	BP-8R
J1002	Binding Post, LO (Mfg No. DF31BC)	58474	BP-8B
J1003	Binding Post, LO (Mfg No. DF31BC)	58474	BP-8B
J1004	Binding Post, GND (Mfg No. DF31BC)	58474	BP-8B
---	Shorting Link (Mfg No. 938-L)	24655	BP-6
---	Banana Jack, Red, NULL DETECTOR OUTPUT (Mfg No. 108-745-1)	74970	BJ-3

MISCELLANEOUS PARTS (Cont'd)

Circuit Design	Description	Mfg. Code	Keithley Part No.
---	Banana Jack, Black, NULL DETECTOR OUTPUT (Mfg No. 108-745-2)	74970	BJ-4
M1001	Meter	80164	ME-38
P1001	Line Cord	80164	CO-2
---	Clamp	80164	CC-7
S1001	Rotary Switch, Assembly less components, NULL	80164	15135B
---	Switch Assembly with components, NULL	80164	15136B
---	Skirted Knob Assembly, Null Switch	80164	15110A
S3001	Rotary Switch less components, POLARITY	80164	SW-119
---	Switch Assembly with components, POLARITY	80164	15138B
---	Skirted Knob Assembly, Polarity Switch	80164	14838A
S3002	Rotary Switch less components, RANGE	80164	SW-116
---	Switch Assembly with components, RANGE	80164	15137B
---	Skirted Knob Assembly, Range Switch	80164	14838A
---	Skirted Knob Assembly, Meter Zero Potentiometer	80164	14838A
S3003	Switch Assembly with components, Readout	80164	14869B
---	Dial Assembly, 0-4 Readout	80164	14827A
S3004	Switch Assembly with components, Readout	80164	15114B
---	Dial Assembly, 0-9 Readout	80164	14828A
S3005	Switch Assembly with components, Readout	80164	15112B
---	Dial Assembly, 0-9 Readout	80164	14828A
S3006	Switch Assembly with components, Readout	80164	15111B
---	Dial Assembly, 0-9 Readout	80164	14828A
S3007	Switch Assembly with components, Readout	80164	15115B
---	Dial Assembly, 0-10 Readout	80164	14829A
T3001	Transformer	80164	TR-50

RESISTORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.
R1001	10 MΩ	1%, ½ w	Comp	00327	R12-10M
R1002	1.25 MΩ	1%, ½ w	Comp	75042	R61-1.25M
R1003	100 kΩ	1%, 7 w	WW	91637	R43-100K
R1004	9010 Ω	1%, ½ w	Comp	01661	R12-9010
R1005	93 kΩ	1%, ½ w	Comp	00327	R12-93K

RESISTORS (Cont'd)

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.
R1006	1.11 MΩ	1%, ½ w	Comp	01661	R12-1.11M
R1007	1 kΩ	1%, ½ w	Comp	00327	R12-1K
R1008	100 kΩ	10%, ½ w	Comp	44655	R1-100K
R1009	100 kΩ	10%, ½ w	Comp	44655	R1-100K
R1010	5 kΩ	1%, ½ w	Comp	01661	R12-5K
R1011	5 kΩ	1%, ½ w	Comp	01661	R12-5K
R1012	5 MΩ	1%, ½ w	Comp	00327	R12-5M
R1013	10 kΩ	10%, 2 w	WWVar	12697	RP27B-10K
R1014	1 MΩ	10%, ½ w	Comp	44655	R1-1M
R1015	1 MΩ	10%, ½ w	Comp	44655	R1-1M
R1016	10 kΩ	10%, ½ w	Comp	01121	R1-10K
R1017	1.5 MΩ	10%, ½ w	Comp	75042	R61-1.5M
R1018	330 kΩ	10%, ½ w	Comp	44655	R1-330K
R1019	1.5 MΩ	10%, ½ w	Comp	01121	R1-1.5M
R1020	15 kΩ	10%, ½ w	Comp	44655	R1-15K
R1021	10 MΩ	10%, ½ w	Comp	01121	R1-10M
R1022	100 kΩ	10%, ½ w	Comp	44655	R1-100K
R1023	*100 kΩ	1%, ½ w	Comp	01661	R12-100K
R1024	*1 MΩ	1%, ½ w	Comp	01661	R12-1M
R1025	Not Used				
R1026	10 MΩ	10%, ½ w	Comp	01121	R1-10M
R1027	8.2 kΩ	10%, ½ w	Comp	01121	R1-8.2K
R1028	1.5 MΩ	10%, ½ w	Comp	01121	R1-1.5M
R1029	1 MΩ	10%, ½ w	Comp	44655	R1-1M
R1030	3.3 MΩ	10%, ½ w	Comp	44655	R1-3.3M
R1031	1.2 kΩ	10%, ½ w	Comp	01121	R1-1.2K
R1032	100 kΩ	10%, ½ w	Comp	44655	R1-100K
R1033	220 kΩ	10%, ½ w	Comp	44655	R1-220K
R1034	6.8 kΩ	10%, ½ w	Comp	01121	R1-6.8K
R1035	1 kΩ	10%, ½ w	Comp	44655	R1-1K
R1036	2 kΩ	1%, 1 w	WW	15909	R58-2K
R1037	*40 kΩ	1%, ½ w	Comp	00327	R12-40K
R1038	*400 kΩ	1%, ½ w	Comp	01661	R12-400K
R1039	4 MΩ	1%, ½ w	Comp	00327	R12-4M
R1040	80 Ω	1%, 1 w	WW	15909	R58-80
R1041	500 Ω	10%, 2 w	WWVar	71450	RP3-500
R1042	1.5 kΩ	1%, 1 w	WW	15909	R58-1.5K
R1043	200 Ω	10%, 2 w	WWVar	71450	RP22-200
R1044	10 kΩ	10%, ½ w	Comp	01121	R1-10K
R1045	*10 MΩ	10%, ½ w	Comp	01121	R1-10M

*Nominal value, factory selected

RESISTORS (Cont'd)

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.
R1046	1 kΩ	20%, 0.3 w	CbVar	71450	RP31-1K
R1047	113.6 kΩ	1%, ½ w	Comp	01661	R12-113.6K
R1048	100 MΩ	20%, ½ w	Comp	75042	R37-100M
R2001	180 kΩ	10%, ½ w	Comp	01121	R1-180K
R2002	150 kΩ	10%, ½ w	Comp	44655	R1-150K
R2003	270 kΩ	10%, ½ w	Comp	44655	R1-270K
R2004	1 MΩ	1%, ½ w	Comp	01661	R12-1M
R2005	22 kΩ	10%, 2 w	Comp	01121	R3-22K
R2006	22 kΩ	10%, 2 w	Comp	01121	R3-22K
R2007	1 MΩ	1%, ½ w	Comp	01661	R12-1M
R2008	*52 kΩ	1%, ½ w	Comp	00327	R12-52K
R2009	150 kΩ	1%, ½ w	Comp	01661	R12-150K
R2010	180 kΩ	10%, ½ w	Comp	01121	R1-180K
R2011	270 kΩ	10%, ½ w	Comp	44655	R1-270K
R2012	270 kΩ	10%, ½ w	Comp	44655	R1-270K
R2013	270 kΩ	10%, ½ w	Comp	01121	R1-270K
R2014	270 kΩ	10%, ½ w	Comp	01121	R1-270K
R3001	220 Ω	10%, ½ w	Comp	44655	R1-220
R3002	100 kΩ	10%, 2 w	Comp	44655	R3-100K
R3003	1 MΩ	10%, ½ w	Comp	44655	R1-1M
R3004	1 MΩ	10%, ½ w	Comp	44655	R1-1M
R3005	1 MΩ	10%, ½ w	Comp	44655	R1-1M
R3006	1 MΩ	10%, ½ w	Comp	44655	R1-1M
R3007	5 Ω	3%, 25 w	WW	91637	R30-5
R3008	470 Ω	10%, ½ w	Comp	01121	R1-470
R3009	150 kΩ	10%, 2 w	Comp	01121	R3-150K
R3010	75 kΩ	10%, 1 w	Comp	01121	R2-75K
R3011	33 kΩ	10%, ½ w	Comp	44655	R1-33K
R3012	220 kΩ	10%, ½ w	Comp	44655	R1-220K
R3013	2.2 MΩ	10%, ½ w	Comp	01121	R1-2.2M
R3014	1 MΩ	10%, ½ w	Comp	44655	R1-1M
R3015	600 kΩ	1%, ½ w	Comp	00327	R12-600K
R3016	600 kΩ	1%, ½ w	Comp	00327	R12-600K
R3017	166.7 kΩ	1%, ½ w	Comp	01661	R12-166.7K
R3018	470 Ω	10%, ½ w	Comp	01121	R1-470
R3019	470 kΩ	10%, ½ w	Comp	44655	R1-470K
R3020	1 MΩ	10%, ½ w	Comp	44655	R1-1M
R3021	1 kΩ	10%, ½ w	Comp	44655	R1-1K
R3022	4.7 kΩ	10%, ½ w	Comp	01121	R1-4.7K
R3023	1 MΩ	10%, ½ w	Comp	44655	R1-1M
R3024	10 MΩ	10%, ½ w	Comp	01121	R1-10M
R3025	150 kΩ	10%, ½ w	Comp	44655	R1-150K

*Nominal value, factory selected

RESISTORS (Cont'd)

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.
R3026	680 kΩ	10%, ½ w	Comp	44655	R1-680K
R3027	270 kΩ	10%, ½ w	Comp	01121	R1-270K
R3028	2.2 MΩ	10%, ½ w	Comp	01121	R1-2.2M
R3029	5.6 kΩ	10%, ½ w	Comp	44655	R1-5.6K
R3030	65.4 kΩ	0.1%, 50 w	WW	91637	R73-65.4K
R3031	100 Ω	0.1%, 1 w	WW	15909	R70-100
R3032	1 MΩ	10%, ½ w	Comp	44655	R1-1M
R3033	220 kΩ	10%, ½ w	Comp	44655	R1-220K
R3034	125 kΩ	0.1%, 2 w	WW	80164	15436A-125K
R3035	200 Ω	10%, 2 w	WWVar	71450	RP3-200
R3036	125 kΩ	0.1%, 2 w	WW	80164	15436A-125K
R3037	*4 kΩ	0.1%, ¼ w	WW	80164	15436A-4K
R3038	200 Ω	1%, ½ w	Comp	00327	R12-200
R3039	1.8 kΩ	1%, ½ w	Comp	01661	R12-1.8K
R3040	250 kΩ	0.1%, 2 w	WW	80164	15432A-250K
R3041	1 kΩ	10%, 2 w	WWVar	71450	RP3-1K
R3042	32.32 kΩ	0.1%, ½ w	WW	80164	***
R3043	18 kΩ	1%, ½ w	Comp	00327	R12-18K
R3044	1 kΩ	10%, 2 w	WWVar	71450	RP3-1K
R3045	2.563 kΩ	0.1%, ½ w	WW	80164	***
R3046	192.8 kΩ	1%, ½ w	Comp	01661	R12-192.8K
R3047	1 kΩ	10%, 2 w	WWVar	71450	RP3-1K
R3048	250.9 Ω	0.1%, ½ w	WW	80164	***
R3049	*	1%, ¼ w	WW	01686	R95-*
R3050	*	1%, ¼ w	WW	01686	R95-*
R3051 to R3056**	40 kΩ	0.02%, 1 w	WW	80164	**16318A-40K
R3057 to R3067**	8 kΩ	0.02%, 1 w	WW	80164	**16318A-8K
R3068 to R3078**	1.6 kΩ	0.05%, ½ w	WW	80164	**16318A-1.6K
R3079 to R3089	320 Ω	0.1%, ½ w	WW	15909	R67-320
R3090 to R3099	64 Ω	0.1%, ½ w	WW	15909	R67-64

*Nominal value, factory selected.
**These resistors supplied only as complete matched sets.
***Resistors designated R3042, R3045 and R3046 are supplied only as Resistor Set 14857A.

VACUUM TUBES

Circuit Desig.	Number	Mfg. Code	Keithley Part No.
V1001	12AX7	73445	EV-12AX7
V1002	6CM8	00011	EV-6CM8
V2001	12BH7	86684	EV-12BH7
V3001	12AX7	73445	EV-12AX7
V3002	12AX7	73445	EV-12AX7
V3003	12AX7	73445	EV-12AX7
V3004	12B4A	85599	EV-12B4A
V3005	12B4A	85599	EV-12B4A
V3006	12AX7	73445	EV-12AX7
V3007	OG3	73445	EV-OG3

MODEL 6601A REPLACEABLE PARTS LIST

(Refer to Schematic Diagram 16321B for circuit designations)

TERMINALS

Circuit Desig.	Description	Mfg. Code	Keithley Part No.
J101	Receptacle, hn modified	80164	CS-79
--	Plug, hn, Mate of J101, Mil. No. UG-59A/U (Mfg. No. 7908)	91737	CS-80
J102	Binding Post, HI OUTPUT (Mfg. No. DF31RC)	58474	BP-8R
J103	Binding Post, LO OUTPUT (Mfg. No. DF31BC)	58474	BP-8B

RESISTORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.
R101	2 MΩ	0.1%, 1 w	WW	54294	R91-2M
R102	2 MΩ	0.1%, 1 w	WW	54294	R91-2M
R103	2 MΩ	0.1%, 1 w	WW	54294	R91-2M
R104	2 MΩ	0.1%, 1 w	WW	54294	R91-2M
R105	2 MΩ	0.1%, 1 w	WW	54294	R91-2M
R106	200 Ω	10%, 2 w	WWVar	71450	RP3-200
R107	100 kΩ	0.1%, 1 w	WW	54294	R90-100K
R108	*1 kΩ	1%, ½ w	Comp	00327	R12-1K

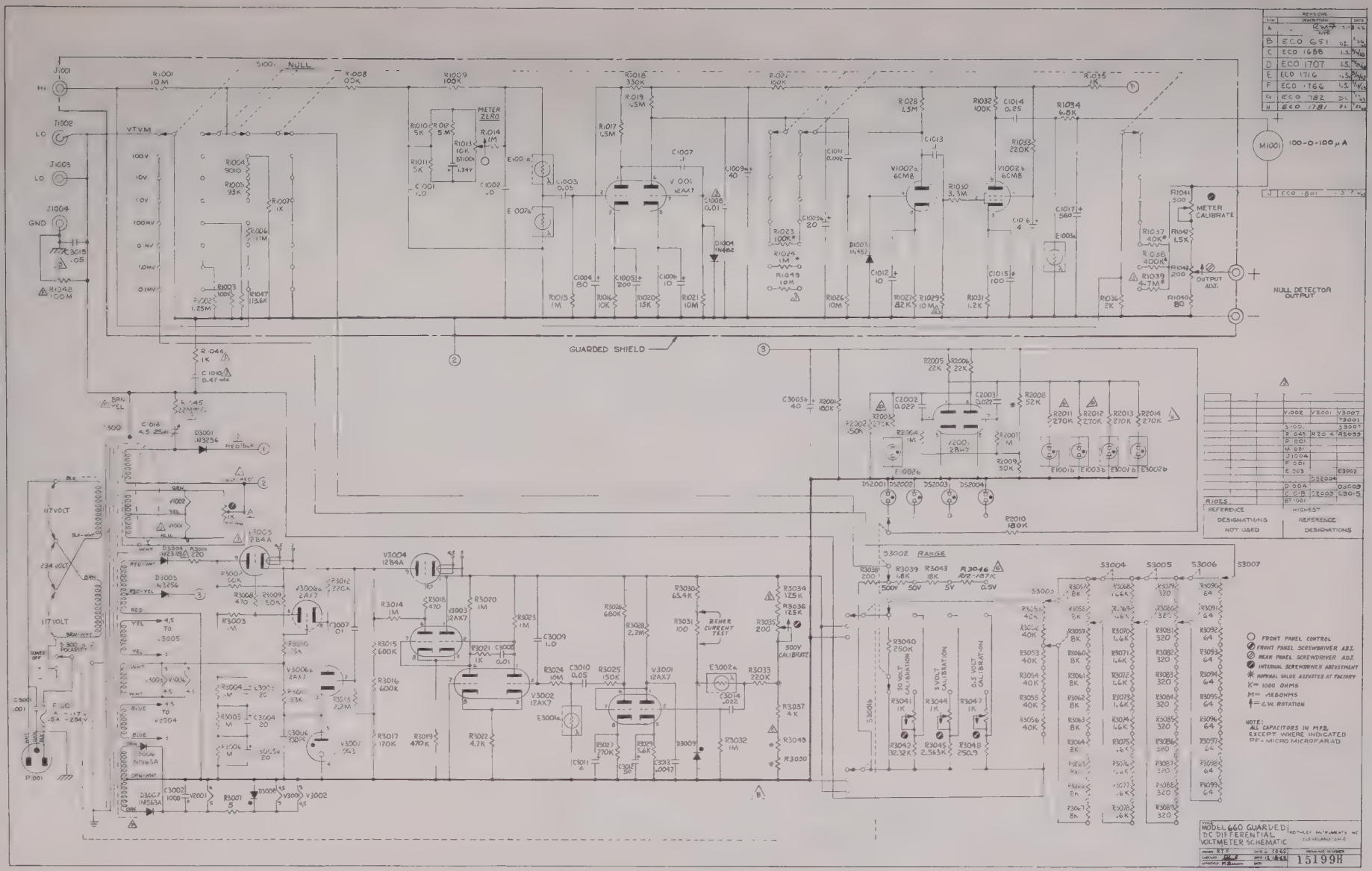
*Nominal value, factory selected.

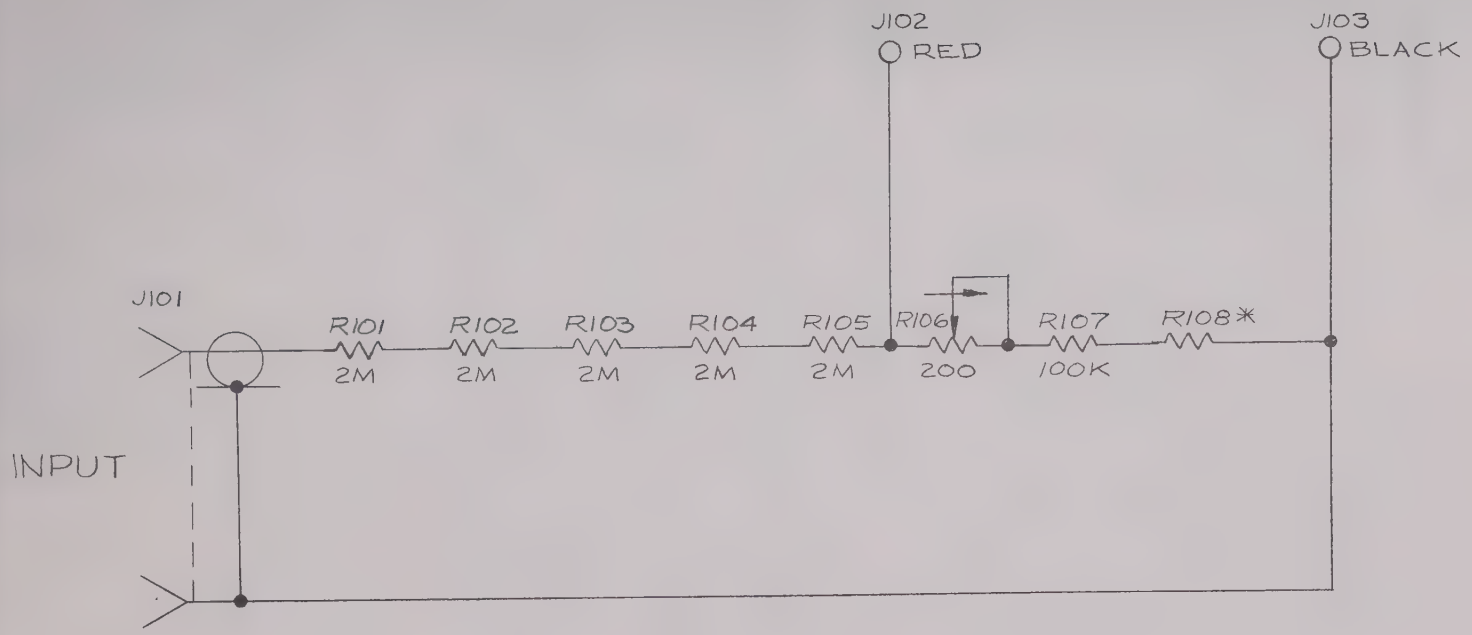
00011	Sylvania Electric Products, Inc. Electronic Tubes Div. Buffalo, N. Y.
00327	Welwyn International, Inc. Cleveland, Ohio
01121	Allen-Bradley Corp. Milwaukee, Wis.
01661	Wilrite Products, Inc. Cleveland, Ohio
01686	RCL Electronics Port Chester, N. Y.
02735	Radio Corp. of America RCA Semiconductor & Materials Div. Somerville, N. J.
02777	Hopkins Engineering Co. San Fernando, Calif.
04713	Motorola, Inc. Semiconductor Products Div. Phoenix, Ariz.
08520	Electronic Devices, Inc. North Ridgeville, Ohio
08804	General Electric Co. Lamp Division Cleveland, Ohio
12065	Transitron Electronic Corp. Wakefield, Mass.
12697	Clarostat Mfg. Co., Inc. Dover, N. H.
13050	Potter Co. Wesson, Miss.
14655	Cornell-Dubilier Electronics Div. of Federal Pacific Electric Co. Newark, N. J.
15909	Daven Co. Livingston, N. J.
24655	General Radio Co. West Concord, Mass.
37942	Mallory, P. R., and Co., Inc. Indianapolis, Ind.
44655	Ohmite Mfg. Co. Skokie, Ill.
53021	Sangamo Electric Co. Springfield, Ill.
54294	Shallcross Mfg. Co. Selma, N. C.
56289	Sprague Electric Co. North Adams, Mass.
58474	Superior Electric Co., The Bristol, Conn.
71450	CTS Corp. Elkhart, Ind.
71590	Centralab Division Globe-Union, Inc. Milwaukee, Wis.
72982	Erie Resistor Corp. Erie, Pa.
73445	Amperex Electronic Corp. Hicksville, N. Y.
74970	Johnson, E. F., Co. Waseca, Minn.
75042	International Resistance Co. Philadelphia, Pa.
75915	Littelfuse, Inc. Des Plaines, Ill.
80164	Keithley Instruments, Inc. Cleveland, Ohio
81453	Raytheon Co. Industrial Components Div. Newton, Mass.
81483	International Rectifier Corp. El Segundo, Calif.
85599	General Electric Co. Schenectady, New York

TABLE 8. (Sheet 1) Code List of Suggested Manufacturers.

86684	Radio Corp. of America RCA Electron Tube Div. Harrison, N. J.	96733	San Fernando Electric Mfg. San Fernando, Calif.
91637	Dale Electronics, Inc. Columbus, Nebr.	99942	Hoffman Electronics Corp. Semiconductor Division El Monte, Calif.
91737	Gremar Mfg. Co., Inc. Wakefield, Mass.		

TABLE 8. (Sheet 2) Code List of Suggested Manufacturers.


MODEL 660 GUARDED
DC DIFFERENTIAL
VOLTMETER SCHEMATIC
KEITHLEY INSTRUMENTS INC
CLEVELAND OHIO
15199H
GUARDED SHIELD
NULL DETECTOR OUTPUT
METER CALIBRATE
OUTPUT ADJ.
100-0-100 μA
S3002 RANGE
S3004
S3005
S3006
S3007
117 VOLT
234 VOLT
FRONT PANEL CONTROL
FRONT PANEL SCREWDRIVER ADJ.
REAR PANEL SCREWDRIVER ADJ.
INTERNAL SCREWDRIVER ADJUSTMENT
NOMINAL VALUE ASSIGNED AT FACTORY
K= 1000 OHMS
M= MEGOHMS
CW ROTATION
ALL CAPACITORS IN MFD. EXCEPT WHERE INDICATED PF= MICRO MICROFARAD
REFERENCE DESIGNATIONS NOT USED
HIGHEST REFERENCE DESIGNATIONS



*850 TO 2000 OHMS

REVISIONS			
LTR.	ECO No.	APPR.	DATE
A			

MODEL	NEXT ASSEMBLY	QUAN
6601A	16267M	1

USED ON

DIMENSIONAL TOLERANCES UNLESS OTHERWISE SPECIFIED		
FRAC.	DEC.	ANG.
± 1/64	± .005	± 1°
DO NOT SCALE		

DRN.	C.F.M.	DATE 042963
CKD.		DATE 4-29-63
ENG. APPR.		DATE 4.29.63
PILOT RELEASE		DATE 4.29.63
PROD. RELEASE		DATE

KEITHLEY INSTRUMENTS
CLEVELAND, OHIO

MATERIAL

FINISH

TITLE
SCHEMATIC, INPUT DIVIDER PROBE

PART NUMBER
16321B

WARRANTY

We warrant each of our products to be free from defects in material and workmanship. Our obligation under this warranty is to repair or replace any instrument or part thereof (except tubes and batteries) which, within a year after shipment, proves defective upon examination.

To exercise this warranty, contact your Keithley field engineering representative. You will be given assistance and shipping instructions.

REPAIRS AND RECALIBRATION

Keithley Instruments and its international distributors maintain complete repair facilities.

To insure prompt repair or recalibration service, please contact your Keithley field representative before returning the instrument.

Estimates for repairs, normal recalibrations, and calibrations traceable to the National Bureau of Standards are available upon request.

CHANGE NOTICE

April 10, 1964 MODEL 660 DIFFERENTIAL VOLTMETER

Page 5-3:

Change to the following:

D1003	Silicon	1N645	01295	RF-14
D1004	Silicon	1N645	01295	RF-14
D3008	Zener	1N1601	81483	DZ-9

Page 5-7:

Change component designated R3046 to a 187 kΩ 1%, 1/2 w, Comp resistor, Keithley Part No. R12-187K

Resistors designated R3042, R3045 and R3048 are supplied only as Resistor Set 14857A.

Page 5-8:

Change to the following:

V2001	12BH7	85599	RV-12BH7

Page 5-9:

Add: 01295 Texas Instruments, Inc.
Semi-Conductor Products Div.
Dallas, Texas

www.manualsplus.com
1036233

KEITHLEY INSTRUMENTS, INC.
12415 EUCLID AVENUE CLEVELAND 6, OHIO